Prediction of Acoustic Environments from Horizontal Rocket Firings

AIAA Aeroacoustics conference – 16-20 June 2014 – Atlanta, GA

In recent years, advances in research and engineering have led to more powerful launch vehicles which can reach areas of space not yet explored. These more powerful vehicles yield acoustic environments potentially destructive to the vehicle or surrounding structures. Therefore, it has become increasingly important to be able to predict the acoustic environments created by these vehicles in order to avoid structural and/or competent failure.

The current industry standard technique for predicting launch-induced acoustic environments was developed by Eldred in the early 1970's and is published in NASA SP-8072[1]. Recent work[2] has shown Eldred's technique to be inaccurate for current state-of-the-art launch vehicles. Due to the high cost of full-scale and even sub-scale rocket experiments, very little rocket noise data is available. Furthermore, much of the work thought to be applicable to rocket noise has been done with heated jets. Tam[3,4] has done an extensive amount of research on jets of different nozzle exit shape, diameter, velocity, and temperature. Though the values of these parameters, especially exit velocity and temperature, are often very low compared to these values in rockets, a lot can be learned about rocket noise from jet noise literature.

The turbulent nature of jet and rocket exhausts is quite similar. Both exhausts contain turbulent structures of varying scale[5,6]—termed the fine and large scale turbulence by Tam[3,7]. The fine-scale turbulence is due to small eddies from the jet plume interacting with the ambient atmosphere. According to Tam *et al*.[4], the noise radiated by this envelope of small-scale turbulence is statistically isotropic. Hence, one would expect the noise from the small scale turbulence of the jet to be nearly omni-directional. The coherent nature of the large-scale turbulence results in interference of the noise radiated from different spatial locations within the jet. This interference—whether it is constructive or destructive—results in highly directional noise radiation. Tam[3] has proposed a model to predict the acoustic environment due to jets and while it works extremely well for jets, it was found to be inappropriate for rockets[8].

A model to predict the acoustic environment due to a launch vehicle in the far-field which incorporates concepts from both Eldred and Tam was created. This was done using five sets of horizontally fired rocket data, obtained between 2008 and 2012. Three of these rockets use solid propellant and two use liquid propellant. Through scaling analysis, it is shown that liquid and solid rocket motors exhibit similar spectra at similar amplitudes. This model is accurate for these five data sets within 5 dB of the measured data for receiver angles of 30° to 160° (with respect to the downstream exhaust centerline). The model uses the following vehicle parameters: nozzle exit diameter and velocity, radial distance from source to receiver, receiver angle, mass flow rate, and acoustic efficiency.

Figure 1 shows the agreement between the measured data and predicted spectra for a small rocket (exit diameter of 0.19 m) at two receiver angles. Figure 2 shows the agreement for a larger rocket (exit diameter of 3.8 m) at similar receiver angles.

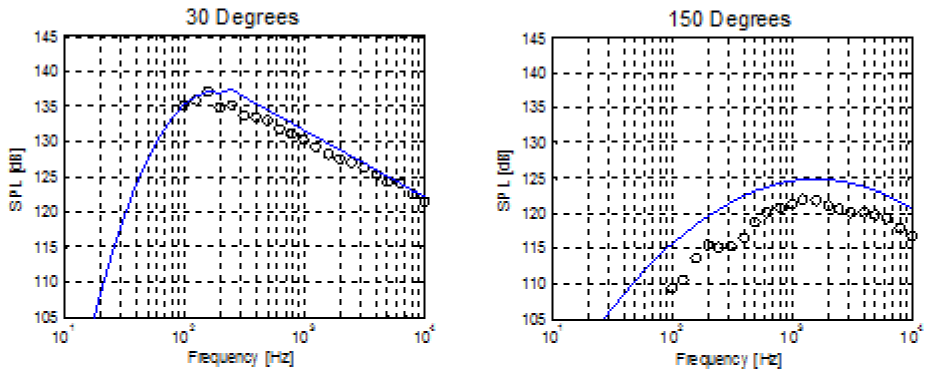

Figure 1: Measured data (circles) and predicted spectrum (line) for a Rocket-Assisted Take-Off motor.

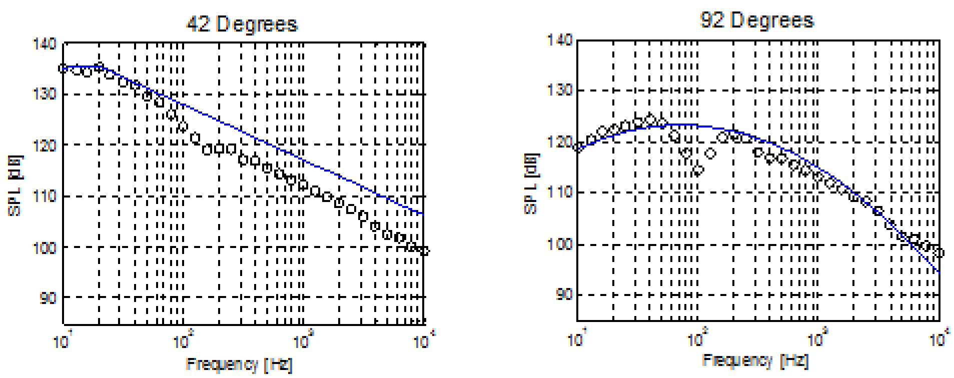

Figure 2: Measured data (circles) and predicted spectrum (line) for a 5-segment Reusable Solid Rocket Motor.

References:

1. Eldred, K., “Acoustic Loads Generated by the Propulsion System,” NASA SP-8072, June 1971.
2. Giacomoni, C., “Comparison of NASA SP-8072 Distributed Source Method II Predictions to Horizontal Solid Rocket Test Data,” ESSSA-FY13-1475, June 2013.
3. Tam, C., Golebiowski, M., Seiner, J., “On the Two Components of Turbulent Mixing Noise from Supersonic Jets,” AIAA-96-1716, May 1996.
4. Tam, C., Viswanathan, K., Ahuja, K., Panda, J., “The Sources of Jet Noise: Experimental Evidence,” AIAA 2007-3641. May 2007.
5. Crow, S. C., and Champagne, F. H., “Orderly Structures in Jet Turbulence,” Journal of Fluid Mechanics, Vol. 48, 1971, pp. 547-591.
6. Brown, G. L., and Roshko, A., “On Density Effects and Large Structures in Turbulent Mixing Layers,” Journal of Fluid Mechanics, Vol. 64, 1974, pp. 775-816.
7. Tam, C., “Mach Wave Radiation from High-Speed Jets,” AIAA Journal, Vol. 47, No. 10, October 2009.
8. Giacomoni, C., “Comparison of a Two-Source Jet Noise Model to Horizontal Solid Rocket Test Data,” ESSSA-FY13-1579, July 2013.